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Machines and the Economics of Growth

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Abstract

This paper summarizes the literature on economic growth. This literature suggests that investment in machinery and equipment (M&E) could foster economic growth. But, because of the need to cover the fixed costs of innovating, price is higher than the marginal cost and there will be underinvestment in M&E in a perfectly competitive economy. Further arguments based on public finance are also made about why there may be underinvestment in M&E.

Résumé

L'auteur fait un sommaire de la littérature sur la croissance économique. Cette littérature suggère que l'investissement dans les machines et les équipements puisse augmenter le taux de croissance économique. Mais parce qu'il y a des coûts fixes à innover, le prix des machines et équipements sera supérieur à son coût marginal et donc, dans une économie parfaitement concurrentielle, il y aura sous-investissement. L'auteur mentionne également d'autres arguments, fondés sur la recherche en économie publique, qui abondent dans le sens d'un sous-investissement en machines et équipements dans une économie en concurrence parfaite.

1. Introduction

In a little over a decade and a half, economic growth has become an area of increasing research for economists. Although economists working in the 1960s, such as Robert Solow, had analyzed economic growth, the underlying causes of long-run growth had remained beyond the scope of their work. Technological growth—innovation—was assumed to be the root cause of growth but this causal actor was unexplainable.

Beginning in 1986 with an article by Paul Romer, examination of the causes of growth moved into high gear. Economists began to endogenize growth: to develop economic models that could explain growth itself. Many avenues were followed, such as the contributions of physical and human capital. However, attention remained focused on innovation and how these types of capital could contribute to the innovative process. This paper will highlight briefly some of the key aspects of modern growth theory, concentrating in particular on innovation, and its implication for economic policy.

The key to growth is innovation in the development of new technology and its diffusion through the economy. Innovation is in large part driven by private firms investing purposefully to develop new technologies. These new technologies may be embodied in new goods—the excludability of these goods gives the incentives for firms to strive to produce new products. But many of the ideas and goods that are produced by firms will be non-rival—they can be reproduced at close to zero marginal cost.

The economic analysis of economic growth has been undertaken at a fairly abstract level. Practical implications are therefore not immediate. Given the attention to innovation and the associated spillovers, tax credits for research and development are the usual policy proposals. But the most fundamental feature of growth is not spillovers or externalities per se but the existence of increasing returns to scale, which implies the prices of innovative goods will exceed their marginal cost. Consequently rates of innovation or of adoption of new technologies will be too low. Increasing returns make spillovers more

likely because replication is cheap, but the fundamental features of the innovation process will lead to a market failure even without spillovers.

This paper will argue that a policy compatible with new growth theory is to have low prices for machinery and equipment, particularly those that embody or lead to new technologies. A policy environment that is not conducive to investment in innovative equipment would exacerbate the negative implication of the pre-existing distortion in the prices of innovative equipment: prices already exceed marginal cost. A policy to mitigate this distortion tackles directly the source of the market failure.

The paper will also discuss other public finance issues related to the theory of optimal pricing of machinery and equipment in a social planner's equilibrium. Firstly, given that machinery and equipment is more likely to be in elastic demand then, in the presence of increasing returns, a lower price is warranted. Secondly, given that these goods are more likely to be financed out of retained earnings than by debt, neutral treatment of the sources of funds is warranted.

Section 2 discusses some of the background to the theory of economic growth and Section 3 discusses some of the empirical evidence on growth and, in particular, the contribution of machinery and equipment. Section 4 makes more concrete those factors that contribute to economic growth. Section 5 discusses some of the tax implications, including more conventional results from public finance theory. Section 6 discusses some of the distributional aspects and Section 7 concludes.

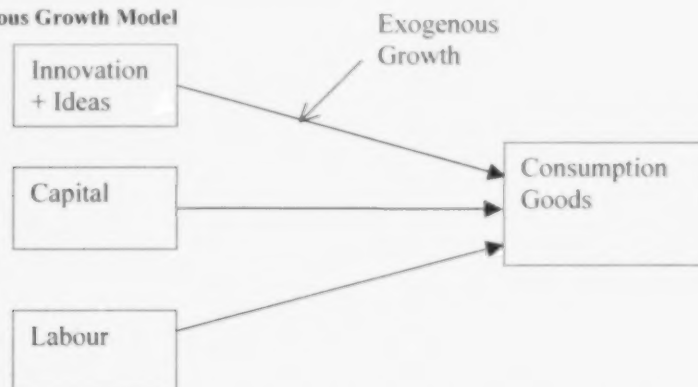
2. History of the Economics of Growth¹

This section briefly looks at the history of the economics of growth. First of all, technology was introduced as an exogenous factor. But work in the last decade and a half has tried to explain growth within an economic model.

a) Neoclassical Growth Model - Solow

Neoclassical growth theory decomposed the growth in output into both technology and conventional inputs. These conventional inputs are labour and physical capital and the employment of these factors responds to economic signals. On the other hand, technology changes that lead to higher productivity growth appear exogenously. In Figure 1, capital and labour are both used to produce final goods for consumers. But the growth of these two factors cannot explain long run growth because of diminishing returns: more and more capital combined with the same amount of labour cannot endlessly lead to growth. Increasing capital through investment leads to short-term change but no long-run growth. Growth arises from innovation and ideas (and population growth) but these are exogenous to the model: they are not explained.

Figure 1: Exogenous Growth Model



Advocates of exogenous growth theory recognized that innovation was key but innovation was exogenous to the model. Implicitly, innovation was modelled as a pure public good. Ideas were generated and could be absorbed costlessly by firms. Because

¹ Some parts of this section draws on the symposium on new growth theory in the *Journal of Economic Perspectives* 8, 1, pp. 3-72 and from Barro and Sala-i-Martin (1995).

innovation is exogenous there are no market failures and, consequently, there is no explicit role for government in the Solow growth model.

Endogenous growth theory on the other hand regards ideas and innovations that engender technology changes as being explainable within the system.²

b) The Beginnings of Endogenous Growth - Spillovers

At first, new growth theorists modelled growth as being generated as an accidental by-product of firms' activities. Technology was explicitly modelled as a pure public good, which, in this case, had the advantage of being compatible with a perfect competition framework. But at least technology was now examined within the context of the model and was explainable. If firms increased their expenditure on capital or labour then some technology spillovers would be generated inadvertently that would lead to economic growth.³ Alternatively, highly skilled individuals would, as a by-product, generate new ideas that would also grow the economy.⁴ Because of these increasing returns that are external to the firm, *à la* Marshall, economic growth occurs. However, this growth was in some sense "accidental"—it was not produced consciously.

Figure 2: Initial Endogenous Growth Model

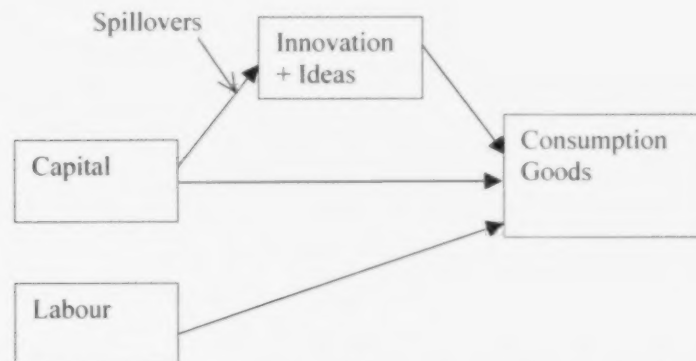


Figure 2 captures this formulation. Capital and labour are again used to produce final goods but now spillover effects generated from capital investment lead to growth.

² An implication of the Solow model is that growth is only a function of exogenous technology change. For evidence rejecting this conclusion, see Bernanke and Gurkaynak (2002).

³ This is the basic framework of Romer (1986).

⁴ See Lucas (1988).

Growth is now explained within the model and the rate of growth is endogenous but it does not result from intentional acts by economic agents.

c) Endogenous Growth —Purposeful Innovation

With further thought, however, economists began to abandon the belief that technological advance was a pure, unintended spillover.⁵ Although science may progress exogenously through the activities of academics, profit-maximizing firms also generate ideas and intentionally allocate resources to the creation of new ideas. Product innovations as well as new inventions are important in economic growth. Furthermore, the commercial application of scientists' discoveries are motivated by profit.

As Paul Krugman and Elhanan Helpman said⁶,

...it is possible to argue that there are external economies resulting from the inability of firms to appropriate knowledge completely. Information gained by one firm, whether explicitly through R&D or through experience, will often be acquired by the firms through word of mouth or deliberate 'reverse engineering'. This is a true externality; however, it is hard to envisage it leading to a relationship [with constant returns]. In the first place innovative industries will ordinarily not be perfectly competitive.

...

Despite these criticisms the external economies approach to incorporating increasing returns remains useful. It should, however, be demoted from its traditional position as the basic approach to trade with economies of scale.

Incorporating purposeful innovation explicitly in the analysis opens quite a can of worms because of the non-rival nature of new ideas. (See Figure 3 for explanations of the terms used in this section). At a minimum, the implications of imperfect competition need to be examined. Firms producing innovative goods operate in a world of imperfect competition because innovation requires up-front costs that are large in relation to the costs of

⁵ Romer, (1990). See also Romer (1987).

⁶ pp. 37-39, Helpman and Krugman (1993).

producing subsequent units. These fixed costs of innovation have to be covered subsequently by mark-ups over marginal cost.

Complications arise because of the nature of the goods produced and the implied institutional structure. Firms undertake research and development and produce new goods because they want to obtain profits. Profits may be obtained only if the ideas that they produce are at least partially excludable, i.e. it is possible to prevent others from copying the product (through use of the patent system, for example).

But furthermore, unlike physical goods (such as a cup of coffee), ideas are non-rival: other people can use new ideas without lowering the quantity available. Because new ideas are non-rival, other firms will benefit from spillover effects. Even though the invention of the transistor was itself protected by a patent, other advances emanating from the existence of a transistor were not precluded. Because the idea of a transistor was non-rival, other inventions could flow from it. As Kenneth Arrow said, "With suitable legal measures, information may become an appropriable commodity. Then the monopoly power can indeed be exerted. However, no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information. The very use of the information in any productive way is bound to reveal it, at least in part."⁷

⁷ Quoted in Grossman and Helpman (1992).

Figure 3: Rivalry and Excludability

Rivalry and Excludability

A key to understanding the origins of growth in the new growth theory is the distinction between rivalry and excludability. Rivalry implies that there is only one consumer of a good. Only one person can drink a cup of coffee hence coffee is rival. However, the idea of the Internet can be 'consumed' by all, hence this idea is non-rival. Many if not all ideas are non-rival.

On the other hand excludability is a feature of the institutional structure. A transistor had patent protection hence its consumption was excludable. Without paying a licence fee it was not possible to procure a transistor. However, the idea of the transistor remained non-rival. Other firms could make advances on the transistor because the idea was in the public domain.

To emphasize these points consider the following table.

	Rival	Non-Rival
More excludable	Cookies	Cable-TV Signal
Less excludable	Fish in the Sea	Pythagoras Theorem

Only one party can consume rival goods but the degree of excludability may vary. Fish in the sea may only be caught once but because of the difficulty in enforcing property rights the catch may not be excludable.

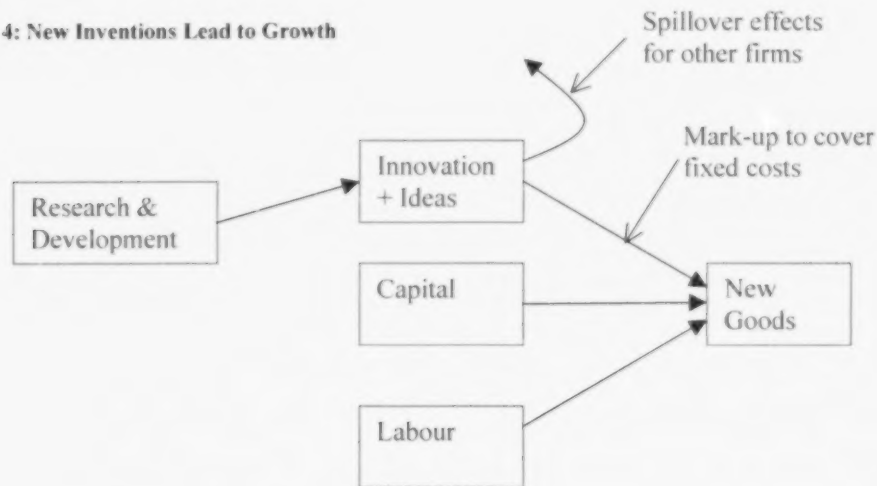
The key drivers of economic growth on the other hand are non-rival. Many households can use a cable television signal. The producer can block the signal so the signal is excludable. On the other hand everyone can use mathematical advances without diminishing their usefulness to others.

Romer(1990) developed a model where knowledge was at least partially excludable, i.e. a firm had a monopoly on its new idea but other firms could introduce new advances based on that idea. In this new formulation, firms now have an incentive to invest consciously in new technologies because the ideas can then be embodied in new products. But because knowledge was only partially excludable, other firms can obtain benefits from the innovating firm's efforts.⁸ In Figure 4, firms invest in research and development in order to find new goods or new methods of production in order to sell to their customers. The investment is expensive and constitutes a fixed cost for the firm. If the new good produced is excludable through patents, the price of the goods will exceed marginal cost.

⁸ Note that the goods themselves could be completely excludable.

However there will also be spillovers from this new technology that the firm cannot capture. For example, the increased adoption of computing power by the logistics industry led to just-in-time delivery and hence to further spillovers.

Figure 4: New Inventions Lead to Growth



Within this framework there are two reasons why innovation is too low. Firstly, firms do not capture the benefits of the spillover effects. Secondly, the monopoly mark-up lowers the rate of adoption and diffusion. Since price is greater than marginal cost, there is in effect a 'private tax' that implies that demand will be too little. Firms will therefore undertake too little research and development.

It is important to note that spillovers are an implication of the argument but they are not central. The key issue is that innovation—the production of new ideas—leads to non-rival ideas. Whether the goods themselves are perfectly excludable or not does not form the crucial part of the argument. The non-rival nature of ideas implies that the benefits will spill over but this is an implication not a cause. The fundamental insight is that non-rivalry means that the advance of ideas will lead to the same amount of inputs (labour, capital) producing more and more output. Consequently there are non-convexities in production, irrespective of the excludability of the goods produced. Such non-convexities

imply that the social welfare theorems do not hold and the market equilibrium is sub-optimal.

As Romer(1990) has noted,

A related argument is that departures from the perfect market assumptions must be small if there is no evidence of spillovers or external effects. What the evidence is on spillovers is not entirely clear. In any case, the logic of the argument is wrong. An economy with perfect patent protection for ideas must exhibit departures from price taking. Patents are supposed to create monopolies. Even if patent protection is perfect and there are no external effects and no spillovers, the associated equilibria will generally not be Pareto optimal. (For an example of an economy of this type, see my 1987 paper.)

The latter point, that the non-rival nature of growth inherently leads to a violation of the requirements of both welfare theorems, means that standard neo-classical intuition about policy no longer holds, as Chicago-trained economists such as Romer and Robert Lucas have been at pains to point out. In particular, there is no presumption that distortions are necessarily welfare-reducing. Distortions that favour the contributors to long-run growth will be welfare-enhancing.

d) The Role of Capital

In Figure 4, expenditure on research and development, the driver of growth in that analysis, occurs independently of capital.⁹ Philippe Aghion and Peter Howitt, who were responsible for seminal early work on R&D and growth, argue however that omitting capital in the growth process is mistaken: "technological progress cannot be sustained indefinitely without the accumulation of capital to be used in the R&D process."¹⁰

Why would machinery and equipment investment foster economic growth? First of all, new equipment may embody innovation. There is a large literature on the embodiment of technological change, starting with Solow, who argued that, "Many, if not most innovations need to be embodied in new kinds of durable equipment before they can be

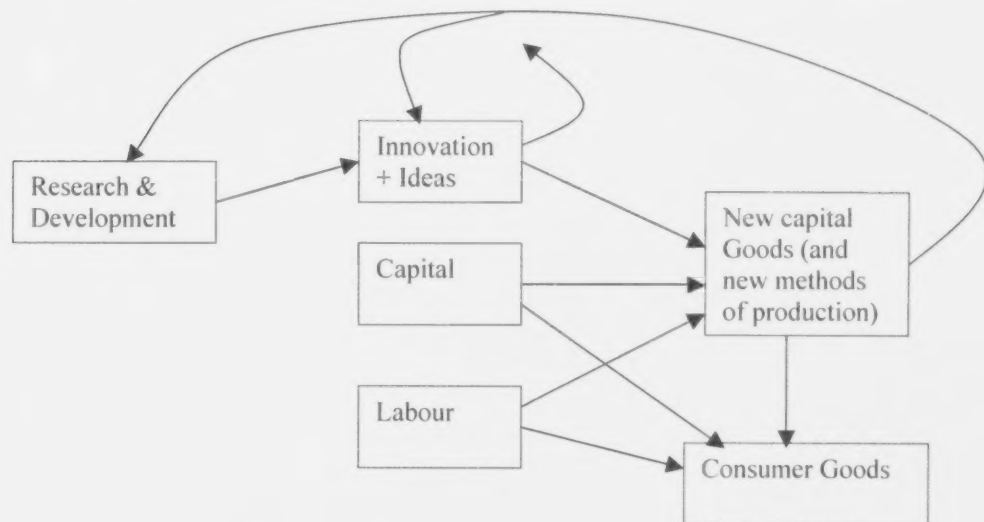
⁹ In Romer (1990) research and development is a function of human capital and the existing stock of knowledge but these assumptions seem to be more for analytic simplicity.

¹⁰ Howitt and Aghion (1998).

made effective".¹¹ Secondly, adopting new technologies usually requires large amounts of capital, training and reorganization. Making capital more expensive to acquire may decrease the desire to adopt new technologies.¹²

Figure 5 develops Figure 4 further. Now innovation and invention lead to new capital goods being developed. But these capital goods themselves feed into the innovative process. As in the case of Just-in-Time delivery mentioned above, computers initially led to a new way of undertaking logistics but then improved logistics enabled the Dell business model and more efficient production of computers. Furthermore capital goods are themselves used in research and development, particularly if one considers research and development as encompassing process innovations.

Figure 5: Role of Machinery and Equipment in Growth



Data from the OECD show that the machinery and equipment, instruments and transport equipment industries account for over a half of all R&D across an average of OECD

¹¹ Solow (1960).

¹² Greenwood et al. (1997) argue that large amounts of the growth of capital stock reflect an endogenous response of capital accumulation to technological change.

countries, as well as more than half in Canada.¹³ Two-thirds of German R&D is done in these industries. But together these industries account for only 6.5 per cent of GDP in Canada, which shows how R&D is concentrated in a few industries. Purchasing goods produced in these industries is equivalent to an implicit demand for R&D.

e) Latest Developments

It should be emphasized that growth theory remains a young and evolving field that has come in for some criticism when faced with actual data (as part of the usual scientific process). This section reviews some of the latest developments but these are not crucial to the underlying story. One of the implications of the literature above was that simply increasing the amount of R&D would increase growth (although this aspect was not emphasized at the time): that there are 'scale effects'. However, the vastly increased resources devoted to research and development over the last decades does not seem to have had any impact on growth rates (Jones (1995)).

For example, Ricardo Caballero and Adam Jaffe (1993) found that the average size of a patent (i.e. the number of ideas encapsulated in the patent) has been declining since the 70s. Furthermore the potency of spillovers has declined. They argue that the marginal product of the public knowledge stock declined by 30 per cent from the 60s to the 90s, which approximates the decline in research productivity. The ratio of patents to other research inputs has declined steadily since the 50s.

Philippe Aghion and Peter Howitt (1992) developed a model that could be used to explain some of these stylized facts by introducing Schumpeter's notion of creative destruction into the modern growth literature. The idea here is that new products are improved versions of existing products. Firms have incentives to develop these products because they can capture the rents that go to the producers of existing products. But this transfer of rent from old producers to new producers is not socially beneficial and so there is an

¹³ This data is for 1999 and comes from the OECD R&D Expenditure in Industry Database. Wilson (2002) shows that the R&D embodied in equipment produced in these industries is much higher than for other goods (his Figure 1).

excessive incentive for new investment. On the other hand, the realization that even newer goods in the future may supersede new products lowers the rate of innovation.

Recalling our earlier discussion of the benefits of new products and the beneficial growth that such products generate, a distinction can be drawn between innovations that lead to new products and innovations that lead to quality improvements. Quality improvements generate new rents because they lead to obsolescence of older products. Consequently there may be excessive investment in quality improvements. On the other hand, entirely new goods are more likely to be introduced through basic research or new methods of operating. There may be too little investment in research and development to develop these new breakthrough products.¹⁴ These two features have been used to explain the absence of scale effects. The composition of R&D is distorted, so that there are too few fundamental breakthrough products. So, as the number of products or sectors expands, the amount of research done in each sector does not change and hence the growth rate of the economy is independent of population growth.¹⁵

This newer strand in the literature maintains Romer's basic insight that non-rival ideas are a source of growth.¹⁶ Most of the new literature introduces new refinements on this basic insight in order to try to attain greater concordance with stylized facts. It remains true that price is greater than marginal cost and that consequently there is too little breakthrough innovation. The notion of externalities has been discarded and attention is focused on the fundamental driver of growth, non-rivalry: "This assumption [of increasing returns] reflects the now-common notion that ideas are nonrivalrous or 'infinitely expandable'."¹⁷

¹⁴ See in particular Young (1998) and Howitt (1999).

¹⁵ For a stylized model that captures all of these differences, see Jones (1999).

¹⁶ As maintained, for example, in Jones (2002).

¹⁷ Jones (1999).

3. Empirical Evidence on Growth and Machinery

Endogenous growth shows that growth has to be generated from differences between social returns and private returns, which arise either from externalities (as in the earlier literature) or from increasing returns (as in the newer literature). Among the empirical evidence presented in this section, there is evidence that shows that M&E investment contributes to long run growth. Consequently there is some support for the argument that social returns exceed private returns for M&E.

a) Econometric Evidence on International Comparisons

Bradford De Long and Lawrence Summers undertook the initial examination of the linkage between machinery and equipment investment and economic growth.¹⁸ Using cross-country data for 1960-1985, they find that each extra percentage point of GDP invested in equipment is associated with an increase in GDP growth of one third of a percentage point per year. Equipment is measured as "electrical and non-electrical machinery," and hence excludes transportation equipment. Numerous caveats were attached to their result, not least the reliability of the data used and whether the data is really comparable across countries.

Summers and De Long advanced arguments as to why investment in machinery and equipment would increase the rate of growth over the long run.¹⁹ They estimated that the social rate of return to equipment investment is 30 per cent per year with much of this return not being captured by private agents.

In a recent well-known study, Xavier Sala-i-Martin examines which variables may influence growth rates.²⁰ He finds that both equipment and non-equipment investment are strongly and positively related to growth, although non-equipment investment has about a

¹⁸ De Long and Summers (1991, 1992). For negative comments see the associated discussion, pp.200-213. Also see in the same issue, Auerbach et al. (1994) and the Reply by De Long and Summers, pp. 803-807.

¹⁹ De Long and Summers (1991).

²⁰ Sala-i-Martin (1997a, 1997b). For confirmation of these results that equipment investment is important, see Fernandez et al. (2001).

quarter of the effect of equipment investment. This work by Sala-i-Martin builds on previous analysis that found that one of the few positive, robust correlations with growth existed with the share of investment in GDP and also that a correlation existed between investment share and the ratio of international trade to GDP.²¹

It seems that the relationship between machinery and equipment and growth is greater for developing countries.²² Such a finding may arise because total machinery investment includes machinery embodying well-established technologies in addition to more innovative products. Developing countries may be able to take advantage of new and old equipment because they have little of any technology. Jonathan Temple finds that equipment investment is weakly correlated with growth in OECD countries, but strongly so in a large group of developing countries. He estimates the social return to machinery investment to be over 50 per cent and shows that this result is robust to simultaneity bias and does not depend on influential outliers.²³

Although the De Long and Summers results gave rise to some controversy at the time, Temple concludes that, "It is not as easy as it once looked to dismiss the findings of De Long and Summers."²⁴ The fact that results seem to be stronger for developing countries may be because of the all-encompassing nature of the 'equipment and machinery' category in the data. It is likely that purchase of any type of machinery will be of assistance in developing countries whereas growth in developed countries may be fostered more by the purchase of innovative equipment that is subsumed within the 'equipment and machinery' category.

b) Comparisons with the U.S.

Productivity developments in the 1990s, as well as Canada-U.S. comparisons of growth drivers, also provide support for the role of M&E in growth. Although there has been an increase in productivity growth in Canada since 1997, the level of productivity remains below that of the U.S. Most factors that are generally viewed as contributing to economic

²¹ Levine and Renelt (1992).

²² For further evidence see Mody and Yilmaz (2002).

²³ Temple (1998).

growth, e.g. the flows of human capital and total investment, are comparable between the two countries. However, it would seem that the share of business M&E investment in Canada falls short of the share in the U.S. and in many other OECD countries, as seen in Figure 6. The fundamental reasons for this shortfall are unclear but such lower rates of investment may be inhibiting productivity growth.

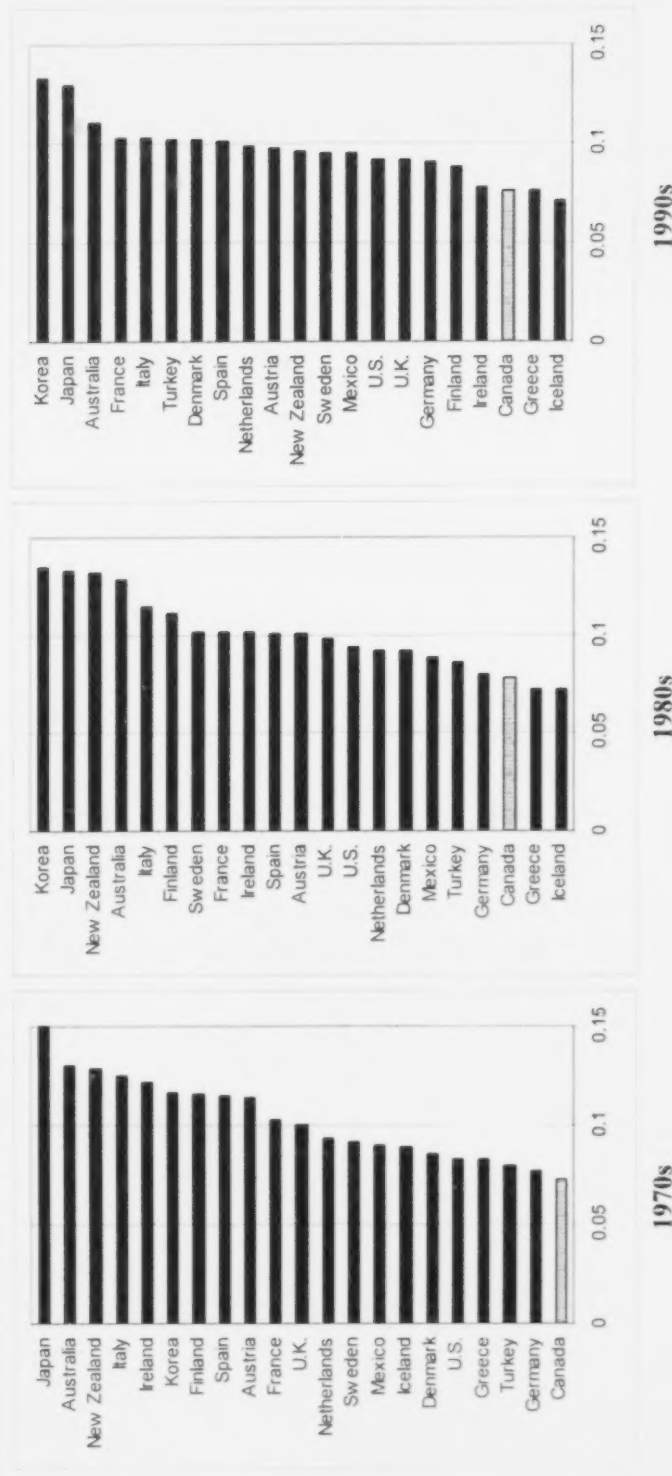
In both Canada and the U.S., there is evidence that productivity growth has accelerated in industries that use information and communication technology (ICT) intensively. This new investment incorporates new ideas and has allowed business to restructure their activities to boost productivity. Benoît Robidoux (2003) reports that manufacturing and service sectors that use ICT intensively grew much faster overall, and that there was a noticeable pick-up in productivity in these sectors post-1997. Finance Canada (2004) reports that average annual growth in labour productivity in Canada increased from 0.9 per cent over 1990-1996 to 2.1 per cent over 1997-2002. The main source of this improvement was the service industries, and the ICT-intensive service industries in particular where productivity growth increased from 1.3 per cent to 3.3 per cent.²⁵

Stacey Tevlin and Karl Whelan (2003) find that in the U.S. the pace at which firms replace depreciated capital has increased and that investment has become more sensitive to the price of capital because of the shift in investment to more technology-intensive equipment. Hence there was a higher rate of replacement investment over the 1990s. This natural market reaction by U.S. firms to falling prices of computers was a proximate cause of the investment boom.

²⁴ Temple (1999).

²⁵ pp. 302, Finance Canada (2004).

Figure 6: Total economy M&E investment-to-GDP ratio, OECD countries



Source: Data for Canada from Statistics Canada, data for U.S. from BEA, for other countries, data from OECD National Accounts, arithmetic averages for each decade.

c) Evidence on Externalities and Increasing Returns

Micro-evidence on the existence of externalities and increasing returns are not easy to come by and are particularly sensitive to the level of aggregation considered (are the estimates at the plant, the firm, the industry or the country level?) as well as to the quality of the data. However, Ricardo Caballero and Richard Lyons(1992) find evidence of externalities at the industry level and that these are driven by a relationship between an industry and its suppliers. The distinction between internal and external economies has not been clearly distinguished in this literature however. Some further research shows that external economies exist but are less prevalent than increasing returns internal to an industry or firm.²⁶

Some further evidence exists on the importance of trade. If trade was an avenue for increasing growth, then imported goods (in particular, equipment that embodies innovation) might be an important means of gaining access to the technological advance of others. Indeed, Helpman and David Coe(1995) find evidence of international spillovers because they find that a country's productivity depends on both foreign and domestic R&D stocks. In particular they find that foreign R&D capital stocks have stronger effects on domestic productivity the larger the share of imports in GDP. Wolfgang Keller(2001) also finds evidence that trade accounts for about two-thirds of the total diffusion of international technology. Furthermore, Gavin Cameron (2000) finds that industries with higher R&D productivities tend to be those with higher capital to labour ratios, higher propensities to use intermediate goods from high R&D industries and higher openness to imports.

d) Conclusion

There is evidence that machinery and equipment affects growth in the long run and this evidence appears to be robust. The results highlighted here could not arise within the context of a neoclassical growth model and can therefore be taken as evidence in favour

²⁶ Henriksen et al. (2001).

of an endogenous growth framework. Micro-level evidence on spillovers exists but spillovers are less central to the endogenous growth argument. In an endogenous growth model the existence of fixed costs from innovating are important and clearly these exist.

4. Policy Implications of New Growth Theory

The main insight of endogenous growth theory is that low private returns on investment, relative to social returns, may have negative implications for growth. This wedge between returns arises because of a fundamental non-convexity driven by non-rivalry. It gives rise to spillover effects and to monopoly pricing of new types of capital goods. Products incorporating innovations are going to be priced above marginal cost and there will be insufficient incentive to produce these goods. Unlike exogenous growth theory, endogenous growth theory implies that government policy may have a role in increasing economic growth rates because of this shortfall in private returns. However, such policies should be considered carefully.

Some of the implications of the mark-up of price over marginal cost can be seen in Figure 5 above:

- a. Capital goods will be too expensive and hence there will be too little demand for innovation and hence for R&D;
- b. R&D will be less efficient because fewer capital goods will be used;
- c. Efficiency in producing consumption goods (new and old) will be too low.

The presence of spillovers from new ideas suggests at first glance that a tax credit for research and development would be warranted. However, it is unclear whether such a policy alone would directly tackle the root cause of the differences in returns—the difference between price and marginal cost. Sala-i-Martin (2001), for example, believes that a subsidy to the purchase of over-priced goods may be better than an R&D subsidy. The shortcomings of an R&D tax credit alone can again be seen from Figure 5: there is too little demand for R&D because of the mark-up. Introducing policies to mitigate the effect of the mark-up would also lead to increased R&D given that R&D is likely to be an increasing function of expected demand. Innovation is a much broader concept than R&D. Many of the new ideas embodied in new investment will not have come from R&D labs, nor are many of the costs associated with developing new ideas necessarily covered by a tax credit.

Furthermore, a key part of our argument is that there is insufficient adoption of new technology, not necessarily production of new goods. Given that capital goods available to Canadian firms often come from other countries (mainly the U.S.), it is not clear that changes to the Canadian R&D credit will do much to affect the price of imported capital goods.

It is unlikely that competition policy would have any significant role to play. Leaving aside the fact that many new ideas—such as just-in-time inventory systems—are inherently difficult to patent, the reason that price exceeds marginal cost is technological (large fixed costs) rather than institutional (market power). The models discussed in this paper assume that there is free entry into the industries that innovate—that the markets are contestable—and a market failure still results.

Given that machinery and equipment may embody innovative ideas, the public economics literature suggests that governments must ensure that public policy does not unduly penalize the purchase of capital goods.²⁷

²⁷ See Barro and Sala-i-Martin (1992).

5. Public Finance and Machinery and Equipment

The story up to now has explained how investment in machinery and equipment may foster economic growth. High prices for machinery and equipment, may inhibit the contribution to growth that machinery and equipment could make. This section will examine more conventional economic arguments to ensure neutral treatment of M&E in a socially-optimal or social planner's equilibrium.

a) Optimal Price Theory

Paul Diamond and James Mirrlees (1971) showed that if the economy is competitive then the social optimum can be attained if input prices are not differentiated between firms. In particular, given that the social optimum can be sustained by only changing prices on final goods, intermediate goods should not be affected.²⁸ Price distortions on intermediate inputs distort factor utilization and change consumption patterns for final goods whereas price distortions on final goods alone only lead to the second distortion. There are exceptions to this rule: ab Iorwerth and Whalley (2002) show, for example, that when it is not possible to change the price of the final good, as in the case of household production, then input price distortions are desirable.²⁹

An assumption in the Diamond and Mirrlees work, which is very pertinent to our current analysis, is that the economy is perfectly competitive. Because of the many forms of introducing imperfect competition into an economic model, one has to be careful in drawing firm conclusions from extensions to models of imperfect competition.

But Konishi(1990) shows, for example, that if an intermediate good produced using constant returns is sold to an oligopolist (producing through increasing returns) and there is free entry, then the intermediate good should have a higher price.³⁰ Furthermore, his research shows that intermediate goods for which there is elastic demand by the final goods producer should have a relatively lower price than goods supplied inelastically: a

²⁸ For a review, see pp. 127 ff. Myles (1995).

²⁹ See also references therein.

production side Ramsey rule. (For evidence that the elasticity for M&E is much higher than for structures, see p. 24 below). Although the Ramsey-rule could be mitigated if cross-price elasticities were large, it would seem to be very unlikely that there are large substitution possibilities between a computer and a building.

Kenneth Judd(1997, 2002) finds some more general results. He argues that imperfect competition in intermediate goods, because innovation is likely to be concentrated there, implies that the price of intermediates is greater than marginal cost. Consequently capital formation should be subsidized in proportion to that distortion. There should be a greater subsidy for goods with higher price-marginal cost margins, and these are more likely to be equipment rather than structures.³¹ Furthermore, he argues that subsidizing the purchase of new capital goods is a more appropriate tool for encouraging R&D than an R&D tax credit alone. R&D will be inherently more biased towards consumption goods. The output of intermediate goods will be too little if imperfect competition is more prevalent in intermediate goods production and hence R&D will be too low for intermediate goods.

b) Marginal Source of Investment Funds

The relationship between public policy and the cost of marginal investment has been a further area of research. The two key questions in this area of research are interlinked: 1) what is the marginal source of funds for investment? and 2) how do firms make investment decisions? Both decisions are connected and both are influenced by public policy.

The view that sources of financing do not matter originates in the Miller-Modigliani theorem, but this notion was quickly discarded after noting that interest payments are deductible but not dividend payouts. Penalizing dividend and capital gains imposes distortions on corporate investment because equity-financed investment would be discouraged.

³⁰ For review see pp. 375 ff. Myles (1995).

³¹ For some evidence that mark-ups on equipment are greater than for construction, see Hall (1986).

The precise source of funds at the margin is still debated. Joseph Stiglitz (1973) argued that marginal investment was likely to be financed by debt so the effect of public policy at the margin was zero. On the other hand, Auerbach (1983) postulated that retained earnings rather than debt are the source of funds at the margin. If this were the case then penalizing investment from retained earnings would change the value of the firm but would not change marginal burdens. Consequently penalizing dividends has no impact on the investment incentives of firms.³²

The fundamental distortion however is the deductibility of interest expense. This feature has noticeable consequences for firms' decisions and their incentives for financial planning, as found in work by Jeffrey Mackie-Mason, for example.³³ John Graham (2000) finds that the capitalized benefit of debt equals 9.7 per cent of firm value.³⁴ Evidence of firms taking advantage of the debt shield can be found in the leasing industry where there exists an incentive for firms to lease assets.³⁵ Firms also use hedging strategies to increase debt capacity, with increased benefits averaging 1.1 per cent of firm value.³⁶

The preceding logic can be extended to argue that the public policy will affect different firms' investments asymmetrically because different forms of financing may be used for different assets. Structures are more likely to be financed by debt, and therefore be less burdened. For equipment, on the other hand, there may be a) no resale market and/or b) a lemons problem (because of uncertain quality) if the equipment was sold. These combine to suggest that equipment investment is at least partially irreversible.³⁷ Even in a distortion-free economy Andrew Abel and Janice Eberly (1999) find that anticipation that investment will be irreversible implies that the capital stock of such goods will be lower. But such equipment may also be poor collateral for debt and therefore be more likely to be financed by retained earnings and thus face a higher burden on the marginal

³² For an overview and some empirical evidence on this question, see Auerbach and Hassett (2000).

³³ For example, Mackie-Mason and Gordon (1990).

³⁴ See also Kemsley and Nissim (2002) and Gordon and Lee (1999).

³⁵ For evidence that this indeed is what happens, see Graham et al. (1998).

³⁶ Graham and Rogers (2002).

³⁷ For evidence on the irreversibility of equipment investment, see Figure 8 in Caballero et al. (1995).

investment.³⁸ For example, Sheridan Titman (1984) postulates that firms producing unique products (as characterized by high R&D expense amongst other things) should use debt conservatively in order to keep the probability of liquidation low thus avoiding potentially large costs for customers.³⁹

These arguments lead one to conclude that there is likely to be a market distortion discouraging equipment investment and this distortion is exacerbated by the preferred treatment of structures investment at the margin. Bronwyn Hall (1992) finds that debt is not favoured as a form of finance for R&D-intensive firms because of both the irreversibility arguments (lemons problem, unwillingness to lend by banks and furthermore the unwillingness to reveal ideas) and the tax system in the U.S. She finds that, "both R&D and interest expense generate expense deductions against current profits ... However, they appear to be substitutes rather than complements."

In Auerbach(1987)'s evaluation of the 1986 Tax Reform Act in the U.S., he concludes, "if corporate structures were more heavily financed than equipment investment ... the new law would still be found to favor structures, since the tax benefits of debt finance have been reduced but not eliminated: the taxes imposed on a corporation in delivering returns to individuals are still lower for debt than for equity."

On the second question (how do firms make investment decisions), there is some empirical debate as to whether investment is only a function of output or whether it is a function of the user cost of capital. Although econometric debate is continuing on this question, Kevin Hassett and Glenn Hubbard(1996) report that the user cost of capital is more important.⁴⁰ They believe that the elasticity of investment with respect to the user cost of capital is between -0.5 and -1.0 . Some authors have suggested that these

³⁸ This argument was advanced in Auerbach (1983b).

³⁹ Titman (1984). For empirical support of this finding, see Titman and Wessels (1988).

⁴⁰ Older analysis used aggregate data but such data is susceptible to simultaneity bias. Increased use of micro data sets and corrections for measurement errors have alleviated these problems.

elasticities may be a bit high (their estimate is -0.25)⁴¹ but subsequent work by the same authors have found higher elasticities (at -0.40).⁴²

The empirical investigation of the user cost of capital has focused on equipment investment. As Kevin Hassett and Glenn Hubbard (2002) note, "we focus on equipment investment, in large part because empirical attempts to model investment in structures have been more disappointing. ... Structures investment is less clearly correlated with all of the 'fundamentals'. The correlation with the user cost is insignificant and has the incorrect sign, the correlation with cash flow is about one-fourth of that between cash flow and equipment investment, and the accelerator effect, while still noticeable, is significantly weaker." However, there seems to be consensus that the elasticities for equipment is much higher than for structures. Stacey Tevlin and Karl Whelan (2003) estimate long-run elasticity for overall capital with respect to the cost of capital of -0.18 but obtain an estimate of -1.59 for computers. However, as pointed out in ab Iorwerth and Danforth (2004), one has to be careful when analyzing macroeconomic data about whether the firm is seeing a permanent decline in the relative price of investment. If structures investment shows no long-term time trend then it is likely that its elasticity will be underestimated.

Such problems with macroeconomic data have led to the use of plant-level microeconomic data where price changes brought about through tax changes are more likely to be perceived as permanent. Cummins and Hassett (1992) estimate that elasticities are -0.23 for equipment and -0.07 for structures. Caballero *et al.* (1995) find elasticities for equipment average -1.0 and conclude that the U.S. Tax Reform Act of 1986 had a large and negative impact on equipment investment (because of the shift to corporate taxes).⁴³

⁴¹ Chirinko *et al.* (1999).

⁴² Chirinko *et al.* (2002). Analysis from Germany in Harhoff and Ramb (2001) leads to an estimate of -0.42 .

⁴³ Further estimates are discussed in ab Iorwerth and Danforth (2004).

6. Distributional Impacts of Increased Investment

Across many countries, policies to favour capital income has been criticized for being more likely to aid those who own firms, i.e. those who have higher incomes. However, machines can be complements with labour. Improved equipment quality may increase worker productivity and therefore lead to higher incomes for workers who use such equipment. This section highlights recent research that argues that the distributional impact of increased incentives for M&E may be neutral.

Paul Beaudry and David Green (2003) have undertaken research work to try to explain recent changes in income inequality.⁴⁴ They emphasize that the role of physical capital is important in explaining rises in inequality. Insufficient increases in physical capital may have led to a wider income distribution.

The essence of the argument is as follows. The rise in human capital attainment has, in relative terms, lowered the price of those with large amounts of human capital. The lower relative price of human capital has led to endogenous technological change: new organization forms have taken over and new ways of doing business. Capital has therefore been attracted to those individuals with high human capital, increasing their marginal product and therefore their wages.⁴⁵ With insufficient physical capital, capital would have departed from lower technology industries and therefore from those with less skills leading to falling wages for the low skilled.

In comparing Germany with the U.S., Beaudry and Green (2003) claim that Germany has experienced a greater relative increase in physical capital. This capital increase in turn may be one of the reasons that Germany has experienced a lower increase in inequality because there was less need for capital to leave the less advanced industries. Hence, they argue, that incentives for the accumulation of physical capital may mitigate rising inequality because of differences in educational attainment.

⁴⁴ See, for example,

⁴⁵ Goolsbee (2003) finds, for example, that a 10 per cent investment tax credit raises the relative wages of capital goods workers, on average, by 2.5-3.0 per cent relative to comparable manufacturing workers.

Francesco Caselli (1999) shows that there has been an increase in the inequality of average capital-labour ratios across industries and those with a large increase in this ratio also experienced large gains in average wages. But other results show that the act of adopting new technology (where these technologies are directly used in the production of manufactured goods) does not dramatically alter the wages paid or the employment structure of plants.⁴⁶ Taken together these results suggest that increased physical investment in equipment would at least not increase wage inequality because increased investment flows may diminish the dispersion in capital-labour ratios but not lead to substantial within plant inequality. Such a result would be especially true if a policy were to target the flow not the stock.

⁴⁶ Doms, et al. (1997).

7. Conclusions

This paper has highlighted some of the key features of the endogenous growth literature that has developed over the last decade and a half. The emphasis in this research has been on innovation and the importance of excludability and non-rivalry. Private firms require excludability in order to have an incentive to innovate. But their innovations are non-rival, which leads to growth. Other firms can benefit from the ideas of the innovating firm. The incentives to innovate are too few because: i) the innovating firms do not get the benefit of the spillovers and ii) firms need to charge a price higher than marginal cost in order to recover their R&D fixed costs.

Because innovative firms charge a price higher than marginal cost, the rates of innovating and diffusion will be low compared to a social optimum. A public policy that favours the adoption machinery and equipment, which are more likely to embody innovations, can therefore be supported. The paper argues also that there may also be more conventional public finance arguments for supporting policies that favour machinery and equipment investment.

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